Modeling High Spatial Resolution Images of Protostellar Disks

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Internally illuminated disk

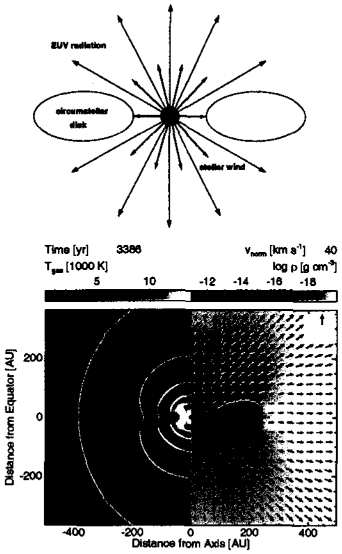

Fig. 1: *Quasi-steady state density, temperature, and velocity structure of a disk and its surroundings illuminated by EUV photons from the central massive star.*

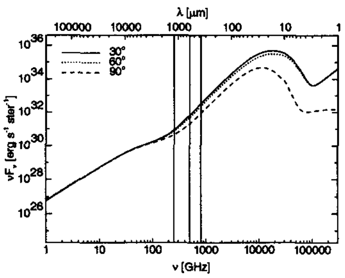

Fig. 3: SED of the massive disk shown in Fig. 1.

Introduction

The evolution and appearance of circumstellar disks in star forming regions are influenced strongly by the radiation from either the central star itself or close companions and nearby hot stars. UV radiation can heat the outer layers of the disk and induce expansion up to escape velocities. Hollenbach et al. (1999, PPIV, in press) consider this "photoevaporation" of disks as a principal, if not the most important, disk destruction mechanism.

Physical Model and Numerical Methods

We have previously performed axially symmetric radiation hydrodynamic calculations of the evolution of internally (Fig. 1; Richling & Yorke, 1997, A&A, 327, 317) and externally (Fig. 2; Richling & Yorke, 1999, ApJ, in prep.; Richling & Yorke, 1998, A&A, 340, 508) UV-irradiated disks. These simulations provide us with the distributions of gas density, temperature and velocity as well as the dust temperature distribution of protostellar disks undergoing photoevaporation, useful for diagnostic radiation transfer modeling. At selected times we first determined the continuum emissivity (free-free + dust) and scattering (dust) at wavelengths ranging from ~1m to 1μm for each point within our computational grid. Using this source function S_ν we performed ray tracing $dI_\nu/ds = -\kappa_\nu^{ext}(I_\nu - S_\nu)$ for selected orientations and wavelengths, from which we could construct SEDs (Figs. 3 & 4) and maps (Figs. 5 & 6). Line transfer calculations for Hα, [OIII] 500.7nm and [CII] 158μm have also been performed, from which emission line profiles and channel maps can be constructed (not shown); further studies of millimeter radio lines are being conducted. Details of our numerical method for radiation transfer are given in Kessel et al. (1998, A&A, 337, 832).

Fig. 1 shows the structure of the flow from a 1.6 $M_\odot$ disk illuminated by hydrogen-ionizing photons from its central 8.4 $M_\odot$ star ($\log S = 46.89$, S in photons/s). The ionization front (*thick line*) separates the warm, low density, ionized flow from the cool neutral disk. The temperature distributions for gas (color scale) and dust (white lines, $T_{dust} = 100$, 150, 200, 250 and 300 K) are displayed on the left half. The evolving low-mass system displayed in Fig. 2 consists of a 0.6 $M_\odot$ star with a disk of initially 0.4 $M_\odot$ and radius 1000 AU. At the time displayed, $t \approx 60{,}000$ yr, the disk has been photoevaporated to 0.14 $M_\odot$ and radius 250 AU by a nearby (0.1 pc) massive star with EUV/FUV emissivities $\log S(\mathrm{EUV}) = 48.86$ and $\log S(\mathrm{FUV}) = 49.25$. Here the contour lines of the dust temperature distribution are given for $T_{dust} = 20$, 30, 40 and 50 K.

Results and Conclusions

Thermal dust emission dominates the SEDs from ~1mm to 3μm (Fig. 3) or to 10μm (Fig. 4). The short wavelength limit for the dominance of thermal dust emission varies as a function of viewing angle. The long wavelength radio spectrum is what is expected from an ionized wind. Wavelengths around ~1mm are critical for studying the transition from free-free emission to thermal dust emission. Both the ionized gas and the neutral disk are strong mm sources; the apparent disk size and the distribution and relative importance of free-free emission varies as a function of wavelength. In Figs. 5 & 6 we find sharp transitions between a) the neutral, molecular material in the disk, in Keplerian rotation, b) the neutral, mostly atomic outflowing (several km/s) PDR material, and c) the ionized, outflowing (several 10 km/s) HII material. Thus, high resolution line and continuum observations with ALMA combined with detailed modeling will provide important constraints regarding the structure of protostellar disks and their UV environment.

Externally illuminated disk

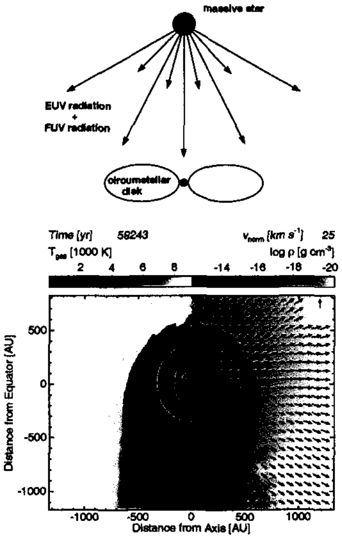

Fig. 2: Density, temperature, and velocity structure of an evolving low-mass system illuminated by EUV and FUV photons from a nearby massive star.

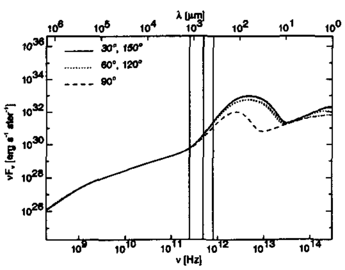

Fig. 4: SED of the low-mass system shown in Fig. 2.

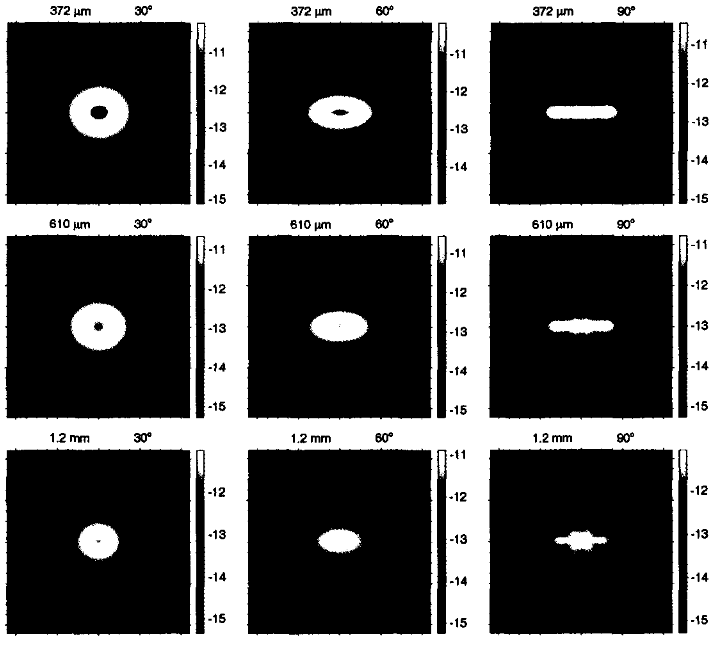

Fig. 5: Continuum maps for massive disk shown in Fig. 1 for wavelengths and viewing angle as indicated. The scale of each frame is 900×900 AU.

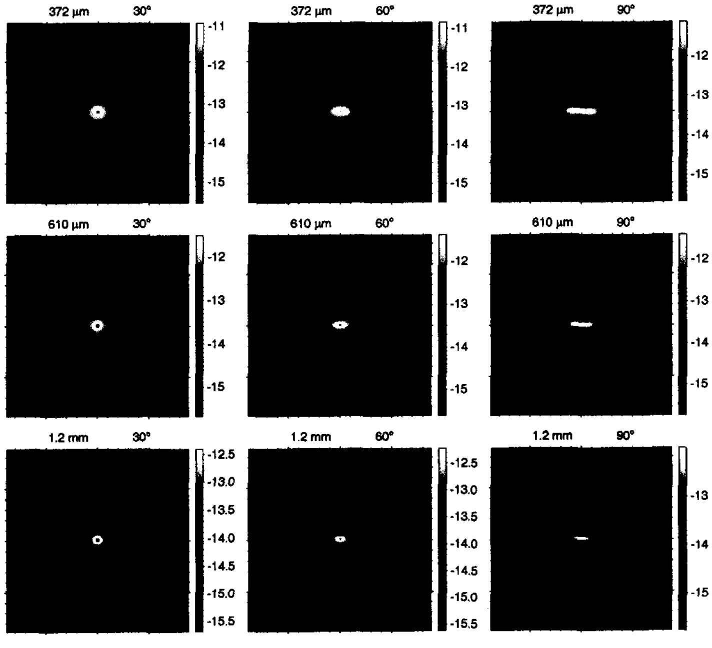

Fig. 6: Continuum maps for the low-mass system shown in Fig. 2 for wavelengths and viewing angles as indicated. The scale of each frame is 1800×1800 AU.